SMALL FORMAT DIGITAL SENSORS FOR AERIAL IMAGING APPLICATIONS

P. M. Dare
Spatial Scientific Technologies Pty. Ltd., PO Box 520, Blackwood, SA 5051, AUSTRALIA
paul@spatialscientific.com

Commission I, Working group I/4

KEYWORDS: Aerial; Multispectral; Data; Acquisition; Geometric; Radiometric; Accuracy.

ABSTRACT:
Small format aerial imaging sensors are important data acquisition tools, but their positive attributes are too often overlooked. Nowadays, as the number of users of spatial data are dramatically increasing, the use of small format sensors is becoming more common. It is therefore important to rigorously assess small format sensors to ensure they are providing quality spatial data. Mostly small format sensors are used for topographic mapping, terrain modelling or multispectral imaging. This paper addresses the last of these three applications, multispectral imaging. The paper compares two different types of small format multispectral sensors, one a commercially available system, and the other a custom built system. It is found that the custom built system, which incorporates consumer grade digital SLR cameras, offers significant advantages over the commercial system.

1. INTRODUCTION

1.1 Background

Small format cameras have long been used for aerial imaging applications (Graham, 1988). Early small format sensors included airborne video, and film based cameras (Everitt, 1991). However nowadays digital cameras are almost exclusively used, whether they be compact, SLR, video or scientific cameras (Dare, 2005). Advances in camera and computer technologies also means that the cost of these cameras is rapidly falling, and hence their use is becoming more widespread.

Traditionally the market for aerial image data has been based around the use of large format cameras. However, as spatial data becomes more widely used, the uses for small format sensors is increasing. Although national or state governments tend to commission the acquisition of data on a regional scale, smaller entities, such as local councils or farmers, are beginning to commission the acquisition of data over much smaller areas.

Very often it is not commercially viable to utilise a large format camera for data acquisition over small areas. Small format sensors however are ideal for mapping small areas, mainly due to their much lower operational cost and greater flexibility. Therefore there are strong reasons to consider small format aerial sensors as important data acquisition instruments.

1.2 Motivation for this study

Advances in imaging technology mean that there are now a plethora of small format sensors that are available for aerial data acquisition. However, the quality of the various sensors and the data they provide can be very variable. The purpose of this paper is to evaluate two different types of small format multispectral sensors: one is a commercial off the shelf system, and the other is a new, custom designed system, which incorporates consumer grade digital cameras.

With the use of small format multispectral imaging sensors becoming more widespread it is important that the tools that are being used provide quality data. If data suppliers rely on inferior instruments, the quality of the data is eroded. The consequences could potentially be very damaging for the spatial information industry.

1.3 Layout of this paper

The next section (Section 2) describes in detail a commonly available and widely used small format multispectral camera – the Redlake MS4100.

The following section (Section 3) presents a new method for acquiring small format multispectral data using a system that is made from two consumer grade digital SLR cameras, one of which is modified to acquire near infrared data.

Section 4 compares the Redlake camera with the proposed modified DSLR system, looking in detail at their geometric, radiometric and logistic attributes. It becomes clear from the comparison that the modified DSLR system has significantly more positive attributes, and therefore has the potential to be an excellent tool for small format multispectral remote sensing.

2. COMMERCIAL SMALL FORMAT MULTISPECTRAL SENSORS

2.1 Background

There are comparatively few small format multispectral sensors commercially available for airborne imaging applications. Many of the sensors that are currently used for airborne remote sensing are custom-built. However, one of the leading brands of multispectral sensors is Redlake (formerly known as DuncanTech) currently marketed by Geospatial Systems Inc. (Geospatial Systems, 2008). The most common Redlake sensor is the MS4100. This is a three CCD, three or four band, single lens digital sensor. It is described in more detail in the following paragraphs.

Also described in this section is the Megaplus range of cameras, also originally developed by Redlake and currently marketed by Princeton Instruments (Princeton Instruments, 2008). These cameras are single CCD, single band sensors.

2.2 Redlake MS4100 multispectral sensor

The Redlake MS4100 is a single lens three CCD, three or four band digital multispectral imaging sensor. A single beam of light passing through the lens is split by prisms so that it falls on the three different CCD sensors. The configuration of those sensors determine the number of bands of the camera. The sensors can be filtered in such a way as to provide three bands of data (one from each CCD sensor), or alternatively, a Bayer filter can be placed in front of one of the CCDs, thus giving up to five bands of data (three from one array and two from the other two arrays). However, as a result the spatial resolution of the Bayer filtered imagery is lower than the other sensors.

The MS4100 has a sensor size of 1920 x 1080 pixels (2 megapixels), with a spectral sensitivity of 8 or 10 bits, depending on how the camera is configured.

Logistically, the MS4100 is a difficult camera to use. It has to be connected to a desktop PC (not a laptop computer) for control and data storage. It also requires an external power supply. The desktop PC also requires a power supply as well as a screen and keyboard. Therefore, not only is there a lot of equipment to install into an aircraft, but also the electrical system of the aircraft has to be modified. On a more positive note, the camera only requires a camera hatch of 3 to 4 inches in diameter.

Section 4 of this paper looks at the geometric, radiometric and logistical specifications of this camera in more detail.

2.3 Redlake MS4100 sample imagery

Figures 1 and 2 show two colour infrared images from the MS4100 sensor. The flying heights at which these images were acquired were significantly different, hence the dramatic difference in spatial resolution.

Figure 1. MS4100 imagery of an urban area

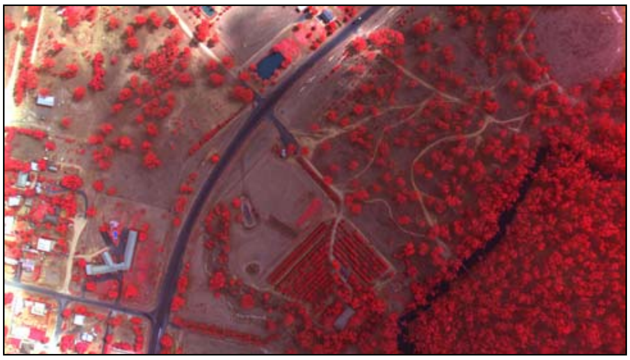

Figure 2. MS4100 imagery of an urban/rural area

2.4 Other Redlake sensors

Another relatively common type of multispectral sensor is a multi-head camera. The camera has separate lens and CCD arrays (“heads”) for each band of data. The Redlake Megaplus system is an example of a multi-head camera.

The advantages of using a multi-head camera is that each lens can be filtered independently of the others, meaning that spectral bands can be changed by simply changing a filter. (The Bayer filter method used by the MS4100 is permanent and cannot be modified.) The disadvantage of this system is that the spectral bands are not geometrically aligned, and the complexity of the overall system is even greater than that of the MS4100.

The Megaplus sensors offer a much larger sensor format than the MS4100: formats up to 4872 x 3248 pixels (or 16 megapixels) are available.

Even so, the cost and complexity of the Megaplus cameras mean they are ill-suited to airborne imaging applications. A much better example of a multi-head camera system is presented in Section 3 of this paper.

2.5 Conclusions

This section has briefly introduced two common, commercial off the shelf, digital multispectral cameras that are available for airborne multispectral data acquisition. However, both of these sensors suffer from weaknesses which can limit their usefulness. Therefore a further type of sensor is discussed in this paper: a sensor composed of two digital SLR cameras. The next section discusses this in more detail.

3. MODIFIED DSLR CAMERAS FOR MULTISPECTRAL IMAGING

3.1 Background

Digital SLR cameras are commonly used in aerial imaging applications (see for example Cunha et al., 2006), but by modifying them they can also be used for multispectral imaging as well.

All sensing arrays in digital SLR cameras are sensitive to near infrared light. However, they have a filter mounted in front of the sensor which excludes near infrared, and therefore preserves the integrity of the natural colour imagery. By removing the near infrared filter, and replacing it with a filter which excludes all light except near infrared, the camera can be used solely for near infrared imaging. This section describes the modification procedure, and the many advantages such a camera has to offer.

3.2 DSLR camera modification

The camera used for the modification in this study was a Canon 350D digital SLR. It has a sensor size of 3456 x 2304 pixels, and a standard, non-removable Bayer filter for separating red, green and blue light. In addition there was a near infrared filter for filtering out near infrared light.

The camera was disassembled, and the near infrared filter was removed. A new Schott RG715 filter, which excludes all light below 700nm, was placed over the sensor. As a result, the camera became sensitive to light over 700nm only.

However, even with the modification, the camera still acquired images with three “bands” of data (due to the presence of the Bayer filter). It was therefore necessary to analyse the spectral sensitivity of the modified sensor to determine which band to use for near infrared imaging. Figure 3 shows the spectral sensitivity of the 350D sensor with no near infrared filter in place. Although it can be seen that all three bands are sensitive to near infrared light, the blue band is most sensitive, and also most separated from the red band. Therefore, the blue band was chosen to be used as the source of the near infrared data.

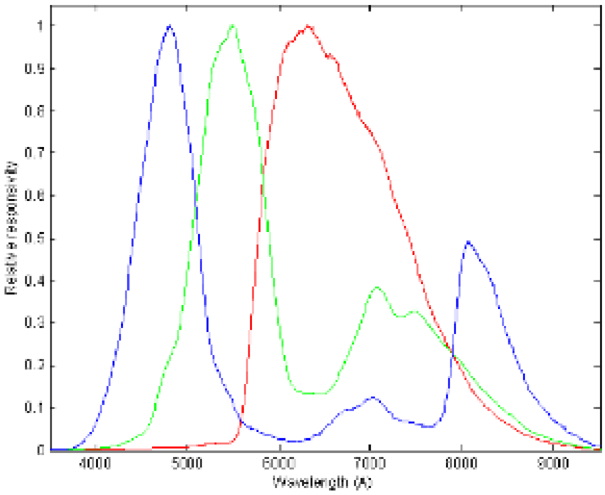

Figure 3. Spectral sensitivity of unfiltered Canon 350D sensor.

It can further be seen from figure 3 that the red, green and blue spectral bands are wide and overlapping. This is a severe limitation for remote sensing applications where narrow, well-defined, non-overlapping spectral bands are required. Therefore, neither a modified nor an unmodified 350D can be used for spectral studies. However, by using two cameras simultaneously (an unmodified one providing red imagery, and a modified one providing near infrared imagery) it is possible to conduct basic NDVI studies. For full spectral analyses using four bands, four cameras would be required: one for each band (including a modified one for near infrared data), and each with an appropriate narrow band-pass filter. In this study two cameras were used: one modified (for near infrared imagery) and one unmodified (for red imagery).

3.3 Camera calibration and inter-band alignment

An issue that has already been raised in this paper, and one that will be addressed again later, is the problem of the geometric alignment of the bands. When using two cameras, the data from each camera needs to be geometrically registered, preferably to sub-pixel accuracy. However, the red and the near infrared data have different geometric distortions due to the fact that two different cameras and two different lenses have been used to acquire the data.

In order to geometrically align the bands as accurately as possible, the geometric distortions need to be accurately modelled. The primary source of geometric distortions come from the lenses. Therefore, each camera was self-calibrated using the iWitness software package (Photometrix, 2008). Table 1 shows the results of the calibration for the two cameras.

	Unmodified Canon 350D	Modified Canon 350D
Focal length (mm)	18.6857	18.6676
PP offsets (mm)	(-0.0575, -0.3323)	(0.1318, 0.0063)
K_1	4.5798e-004	3.8513e-004
K_2	-1.0523e-006	-2.7556e-008
K_3	2.9785e-010	-4.2835e-009

Table 1 Calibration results of unmodified and modified Canon 350D digital SLR cameras.

It can be seen from the values in table 1 that the geometric properties of each camera are sufficiently different to necessitate the rigorous removal of the lens distortions from the imagery. Therefore, before the images were aligned, the lens distortions were removed.

The next most significant source of misalignment errors is due to slightly different pointing angles of the cameras. If the difference in pointing angles is small, then the misalignment could be modelled with a simple first order transformation. However, for large differences in pointing angles, a projective transformation would be required to model the misalignment.

In this study the differences in pointing angles were estimated to be small, therefore an affine transformation was used to register the images. An assessment of the alignment of the bands after registration is presented in Section 4 of this paper.

3.4 Sample imagery

The three images below show sample imagery from non-modified and modified 350D cameras. Figure 4 shows a natural colour image from a non-modified camera, whilst figure 5 shows the infrared band from a modified 350D. The images have been corrected for lens distortions and aligned with each other using an affine transformation. The parameters of the transformation were calculated from points measured manually in both images. As a result of the alignment it has been possible to create a composite image made up of three bands: near infrared from the modified 350D with red and green from the non-modified 350D. The result is shown in figure 6.

Figure 4. RGB imagery from non-modified DSLR camera

Figure 5. NIR imagery from modified DSLR camera

Figure 6. Composite NIR, red, green image

3.5 Conclusions
This section has presented, albeit rather briefly, a methodology for modifying a Canon digital SLR camera so that it can be used to acquire near infrared data. Details have also been presented on how a modified camera and unmodified camera can be used together to create a multispectral remote sensing system. Although only two bands of data can be acquired from such a system (red and near infrared) this is sufficient for basic NDVI studies.

The next section compares the data acquired from the modified DSLR system with the Redlake MS4100, in order to better understand the advantages and disadvantages of each sensor.

4. COMPARATIVE STUDIES

4.1 Introduction
The two systems under discussion in this paper, the Redlake MS4100 and the modified DSLR are compared in three different ways: geometrically, radiometrically and logistically.

The geometric comparison is concerned with the alignment of the different multispectral bands. For reliable multispectral measurements to be made, sub pixel alignment between the bands is normally required. In this study the inter-band alignment has been calculated by measuring the locations of common points selected from two different bands (red and near infrared). The discrepancies in the locations of corresponding points are presented as residuals, and can be interpreted in the same way as any other two dimensional image registration problem. In order to ensure a high number of good quality conjugate points, an automatic image-based matching method was used.

The radiometric comparison was concerned with the spectral properties of the images. Unlike the band alignment, it is much more difficult to accurately quantify the spectral component of the data. However, in order that at least some spectral comparison could be made, NDVI images were created from each data set, and analysed visually.

The logistical and practical implementation of each system is much easier to compare. Aspects of each imaging system, such as power supply, data storage, and camera control were compared for each sensor.

4.2 Geometric comparison
Both the Redlake MS4100 and the modified DLSR were tested for inter-band alignment accuracies. The results of the band alignment tests for the Redlake MS4100 are shown in figure 7 below. (Note that the residuals in this image have been increased in magnitude by a factor of 10 for display purposes.) A total of 300 points were successfully matched between the two bands (red and NIR). Firstly, it is clear that the points are evenly spread across the image, meaning that there is no spatial bias in the results. Secondly, it can be seen that there is no obvious systematic error in the residuals – they are randomly distributed in magnitude and direction. The root mean square residuals for row and column were 1.7 pixels and 1.6 pixels respectively.

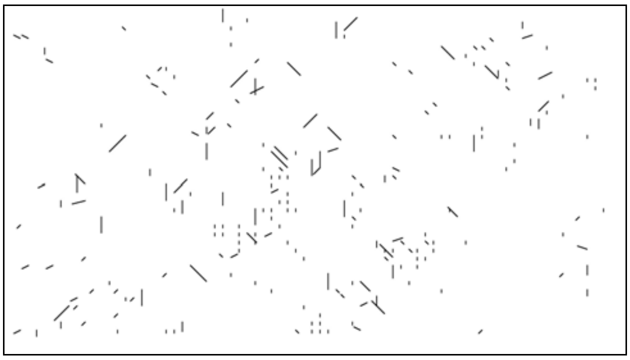

Figure 7. Band alignment residuals for the Redlake MS4100 (Image size is 1920 x 1080 pixels. Residuals not to scale.)

The results of the band alignment tests for the modified DSLR imagery are shown in figure 8. (Note that the residuals in this image have also been increased in magnitude by a factor of 10 for display purposes.) The matching process resulted in 242 successfully matched points between the red and NIR bands. Those matched points were evenly spread across the image, and the residuals again showed random distributions in both magnitude and direction. The root mean square residuals for row and column were 3.6 pixels and 3.7 pixels respectively.

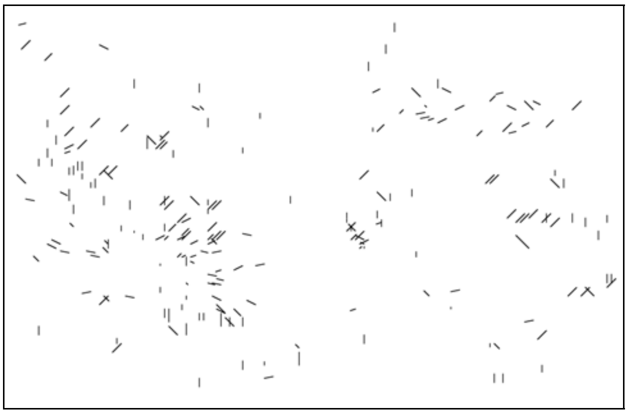

Figure 8. Band alignment residuals for the Canon 350D (Image size is 3456 x 2304 pixels. Residuals not to scale.)

As would be expected, the alignment of the bands for the MS4100 is slightly better than the alignment of the Canon DSLR cameras. In the MS4100, light has to travel through only one lens in order to reach two CCD arrays, meaning that the lens distortions for each band are almost identical. However, with the modified DSLR system, light has to travel through different lenses for each band. Although the imagery has been corrected for lens distortion, it is clear that residual lens distortions, or other distortions remain.

A further point needs to be taken into consideration: the 350D sensor has over four times as many pixels as the MS4100 sensor. Therefore, the Canon images could be reduced in size by a factor of two. This would have the effect of halving the misalignment of the bands, bringing the results for both sensors into line with each other. Even so, the format of the 350D sensor would still be greater than that of the MS4100.

4.3 Radiometric comparison

In order to compare the sensors radiometrically, NDVI images were created from the red and NIR bands. The NDVI for the MS4100 sensor is shown in figure 9, whilst that of the modified DSLR system is shown in figure 10. In each case the NDVI has been displayed as a greyscale image with dark greys representing low NDVI values, and light greys representing high NDVI values.

The target for the radiometric comparison is a sports ground which is approximately the size of a cricket oval. The NDVI highlights differences in the health and vigour of the grass growing on the sports ground. Due to very low natural rainfall in this area, the grass is watered artificially, leading to the non-homogeneous growth patterns visible in the grass.

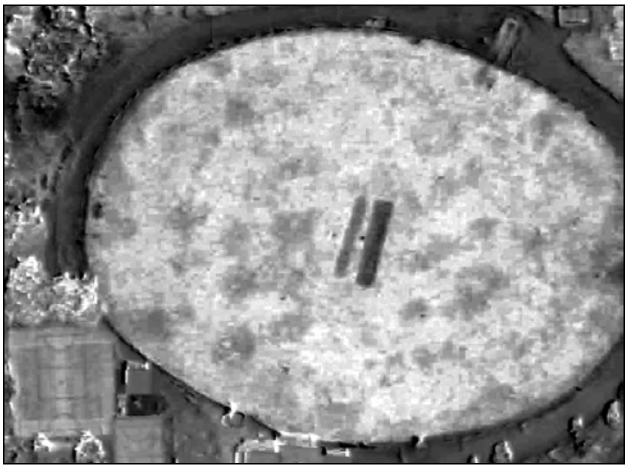

Figure 9. NDVI from the MS4100 sensor

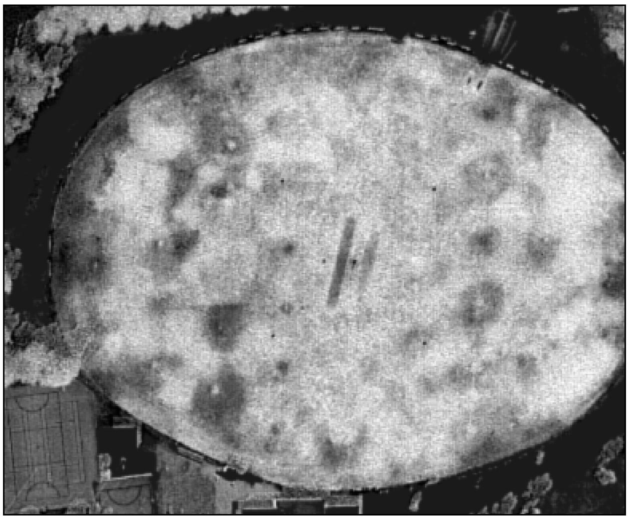

Figure 10. NDVI from the Canon 350D sensor

Whilst it can be difficult to make any in depth analysis of the NDVI images when relying solely on visual inspection and interpretation, it is possible to infer some general themes from the images. Firstly, both images generally display the same spatial distribution of features in the vegetation: the areas of high and low vigour occur in the same places in each image. Secondly, each imaging system is equally sensitive to the variations in grass health and vigour. Neither sensor outperforms the other in the detection of features in the vegetation. Finally, it can be seen that the higher spatial resolution of the Canon imagery leads to finer detail in the NDVI imagery being visible.

4.4 Logistical comparison

The logistical aspects of implementing the two systems are summarised in table 2 below. This table does not include technical specifications of each camera. Only those factors relevant to the use of the sensors are presented.

Redlake MS4100	**Modified Canon 350D**
PC controlled. Cannot be used with a laptop computer – a desktop system must be used	Stand alone system, but can be used with a laptop computer for greater functionality
External power required	Internal power supply
External data storage required	Internal data storage
3 inch camera hatch required	9 inch camera hatch required

Table 2. Factors affecting the practical implementation of the two camera systems.

The great advantage of consumer digital cameras (such as the Canon 350D) is that they have been designed to be reliable, robust and easy-to-use instruments. Firstly they can operate for many hours on their own internal battery, whereas the MS4100 requires an external 12V power supply. Secondly, they can write data to compact flash cards (giving up to 64Gb storage capacity). The MS4100 relies on external storage in the controlling computer. However, most importantly is the fact that the MS4100 is a much more difficult camera to install in an aircraft compared to the Canon 350D. The reason for this is the need for a desktop PC to control the camera (a laptop computer cannot be used). The overhead associated with a desktop PC (screen, keyboard, power supply) makes the installation in an aircraft much more difficult.

One distinct advantage of the MS4100 is that it requires a much smaller camera hatch than the 350D system. Since the latter is made up of two cameras, the hatch needs to be able to accommodate two lenses.

4.5 Conclusions

This section has presented the results of comparative tests between the Redlake MS4100 and the modified DSLR system. It has been shown that the alignment of the bands is better for the MS4100, but the 350D system is much easier to implement. Differences in the radiometric quality of the images have not been investigated in depth, but the visual assessment presented here suggests that the two systems perform equally as well as each other.

The quality of the data from the modified DSLR system could be improved if it were possible to improve the alignment between the spectral bands. This could be achieved through a range of methods, such as: using higher quality lenses, only using the central portion of each image, or developing a more rigorous algorithm for aligning the images (possibly a higher order polynomial rather than an affine transformation).

One final point that should be made, but thus far has not been considered in this paper, is the issue of costs. A Redlake

MS4100 with lens and controlling PC would cost at least US$30,000. The modified DSLR system (including two Canon 350D cameras (one modified) and two lenses) would cost less than US$5,000. Such a substantial cost difference cannot be ignored.

5. SUMMARY

This paper has described the importance of small format digital aerial photography, especially in the field of multispectral imaging. Furthermore it has presented two systems for acquiring small format multispectral data. One system, the Redlake MS4100, is a scientific camera designed for multispectral data acquisition. The other system is built around two consumer grade digital SLR cameras – one modified for near infrared data acquisition, and the other in its standard configuration.

By rigorously comparing the two imaging systems it has been possible to identify which system will provide the highest quality multispectral data. The MS4100 has a small sensing array, and can be logistically difficult to install in small aircraft. However it has good alignment of the spectral bands and only requires a small camera hatch. The modified DSLR system has a much larger sensing array (therefore giving much higher resolution data), but the spectral bands are not so well aligned. The logistical issues of operating a the Canon system in a light aircraft are trivial.

A third system was also briefly mentioned – the Redlake Megaplus camera system. This system does not appear to offer any advantages over the other two systems already described, so it therefore was not investigated further.

In summary, it can be said that the MS4100 is a good spectral instrument, but its small CCD sensor and logistical issues can make its use problematic. The modified DSLR system offers a good opportunity for multispectral imaging, but further research is required to align spectral bands more closely. If this can be achieved, then the combination of modified and unmodified digital SLR could revolutionise the small format remote sensing industry.

6. REFERENCES

Cunha, S., Silvio, S. and Piqueiro, F., 2006. “Photogrammetry in light aircraft.” In proceedings International Calibration and Orientation Workshop EuroCOW 2006, 25 - 27 January 2006, Castelldefels, Spain.

Dare, P. M., 2005. "The use of small environmental research aircraft (SERA's) for remote sensing applications." *International Journal of Geoinformatics* , 1(3): 19-26.

Everitt, J. H., Escobar, D. E., Villarreal, J. R., Noriega, J. R. and Davis, M. R., 1991. Airborne video systems for agricultural assessment. Remote Sensing of the Environment 35: 231-242.

Geospatial Systems Inc. http://www.geospatialsystems.com/ [Accessed April 2008].

Graham, R. W., 1988. Small format aerial surveys from light and microlight aircraft. Photogrammetric Record 12(71): 561-573.

Photometrix. http://www.photometrix.com.au/ [Accessed April 2008].

Princeton Instruments. http://www.piacton.com/ [Accessed April 2008].